

# RARE-EARTH METALS

By James B. Hedrick

The rare earths are a relatively abundant group of 17 elements consisting of scandium, yttrium, and the lanthanides. The elements range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements at 60 parts per million, to thulium and lutetium, the least abundant rare-earth elements at about 0.5 parts per million.

Scandium, atomic number 21, is the lightest rare-earth element. It is the 31st most abundant element in the Earth's crust with an average crustal abundance of 22 parts per million. It is represented by the chemical symbol Sc or the isotopic symbol  $Sc^{45}$ , denoting its only naturally occurring isotope. Although its occurrence in crustal rocks is greater than lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities because it does not selectively combine with the common ore-forming anions.

Yttrium, atomic number 39, is chemically similar to the lanthanides and often occurs in the same minerals as a result of its similar ionic radius. It is represented by the chemical symbol Y or the isotopic symbol  $Y^{89}$ , denoting its only naturally occurring isotope. Yttrium's average concentration in the Earth's crust is 33 parts per million and is the second most abundant rare earth in the Earth's crust.

The lanthanides consist of a group of 15 elements with atomic numbers 57 through 71. In ascending order of atomic numbers, the lanthanides are as follows: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Cerium, the most abundant of the group, is more abundant than copper. Thulium and lutetium, the least abundant of the lanthanides, occur in the Earth's crust in higher concentrations than thallium, antimony, cadmium, and bismuth.

The rare earths were discovered in 1787 by Swedish Army Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine near the village of Ytterby, Sweden. With similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated from ytterbite by Finnish chemist Johann Gadolin. The elemental forms of rare earths are iron gray to silvery lustrous metals and are typically soft, malleable, and ductile. They are usually reactive, especially at elevated temperatures or when finely divided. Melting points range from 798°C for cerium to 1,663°C for lutetium. The rare earths' unique properties are used in a wide variety of applications.

Domestic mine production of rare earths was estimated to have decreased in 1997. Domestic apparent consumption also decreased in 1997, owing primarily to decreased demand for cerium compounds used in automotive catalytic converters and a decrease in demand for other noncerium rare-earth compounds. Earnings by the major domestic processor also reportedly

decreased because of lower margins on lanthanide products, the result of increased competitive pricing from Chinese manufacturers and suppliers (Unocal Corporation, 1998). (See table 1.)

Demand for lanthanides used in petroleum fluid cracking catalysts increased, while those used in automotive catalytic converters declined.

The domestic use of scandium increased in 1997, but overall consumption remained small. Commercial demand increased as additional applications entered the market. Most metal and compounds were sold for use in sporting goods, welding wire, metallurgical research, and analytical standards. Minor amounts were used in specialty lighting and semiconductors.

## Legislation and Government Programs

All stocks of rare earths in the National Defense Stockpile (NDS) were previously sold. However, at yearend 1997 the NDS contained a total of 386 metric tons (425 short tons) of unshipped rare earths contained in sodium sulfate. Previous authorizations for disposal of all stocks of rare-earth materials did not change as a result of the enactment of the National Defense Authorization Act for Fiscal Year 1997 (for FY 1997, Public Law 104-201, enacted on September 23, 1996), and the National Defense Authorization Act for Fiscal Year 1998 (for FY 1998, Public Law 105-85, enacted on November 18, 1998).

## Production

Domestic mine production data for rare earths are developed by the U.S. Geological Survey from a voluntary survey of U.S. operations entitled, "Rare Earths." The one mine to which a survey form was sent did not respond.

The United States remained a major world producer of rare earths in 1997 with only one domestic mine in operation. Domestic production was entirely from Molycorp, a wholly owned subsidiary of Unocal Corp. Bastnasite, a rare-earth fluorocarbonate mineral, was mined by open pit methods at Mountain Pass, CA. Molycorp's mine was the leading producer of rare earths in the United States and second in the world. Mine production was estimated to have decreased from the 1996 level of 20,400 tons of rare-earth oxide (REO).

Three domestic companies refined lanthanides in 1997. Molycorp produced refined compounds from bastnasite at its separation plant at Mountain Pass, CA. Rhône-Poulenc Basic Chemicals Co. (Rhodia Inc. as of January 1, 1998) produced rare-earth compounds from rare-earth intermediate compounds at its facility at Freeport, TX. Grace Davison refined rare earths for petroleum fluid cracking catalysts from rare-earth chlorides and other rare-earth compounds at Chattanooga, TN.

Except for minor amounts of yttrium contained in domestically produced bastnasite concentrates, essentially all purified yttrium was derived from imported compounds.

Three scandium processors operated in 1997. High-purity products were available in various grades with scandium oxide produced up to 99.999% purity.

Sausville Chemical Co. moved its scandium refinery facilities from Newport, TN, to Knoxville, TN, in 1996-97. Sausville expected to produce high-purity scandium oxide, fluoride, nitrate, chloride, and acetate. Joint-venture research partner Recovery Dynamics of Johnson City, TN, located its new refinery facility in Elizabethton, TN (Joseph Sausville, Sausville Chemical Co., oral commun., 1997).

Boulder Scientific Co. processed scandium at its Mead, CO, operations. Boulder refined scandium primarily from imported oxides to produce high-purity scandium compounds, including diboride, carbide, chloride, fluoride, hydride, nitride, oxalate, and tungstate.

Scandium was also purified and processed from imported oxides at Aldrich-APL in Urbana, IL, to produce high-purity scandium oxide, fluoride, and hydrous and anhydrous chloride. Aldrich-APL also produced high-purity scandium metal.

Principal domestic producers of neodymium-iron-boron magnet alloys were Magnequench International, Inc., Anderson, IN; Neomet Corp., Edinburg, PA; and Rhône-Poulenc Basic Chemicals Co., Phoenix, AZ. Leading U.S. producers of rare-earth magnets were Crumax Magnetics, Inc., a subsidiary of YBM Magnex International, Inc., Elizabethtown, KY; Electrodyne Co., Batavia, OH; Electron Energy Corp., Landisville, PA; Hitachi Metals America, Magnetics Materials Division, Edmore, MI; Magnequench International, Anderson, IN; TDK Corporation of America, Mount Prospect, IL; and Ugimag, Inc., Valparaiso, IN.

## Consumption

Statistics on domestic rare-earth consumption are developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths decreased in 1997 compared with that of 1996. Yttrium consumption was estimated at 292 tons in 1997, an increase from the 1996 level. Yttrium compounds were imported from a greater number of sources in 1997 than in 1996. However, China is believed to be the source of most of the world's yttrium ore and compounds. The United States imported yttrium compounds from China, 35.3%; France, 35.0%; the United Kingdom, 22.7%; Belgium, 3.2%; Hong Kong, 3.0%; and Japan, 0.8%. Yttrium was used primarily in abrasives, electronics, lamp and cathode-ray tube phosphors, lasers, oxygen sensors, structural ceramics, and superalloys.

## Tariffs

U.S. tariff rates for rare earths are listed in the Harmonized Tariff Schedule of the United States (1997), Publication 3001, 9th edition, as compiled by the United States International Trade Commission. Publication 3001 is available from the U.S.

Government Printing Office under document serial number 949-013-00000-6. Tariffs schedules for 1998 are listed in the Harmonized Tariff Schedules of the United States (1998), Publication 3066, 10th edition. Publication 3066 is available from the U.S. Government Printing Office under document serial number 949-014-00000-2, or on the Internet at <http://www.usitc.gov/taffairs.htm>.

U.S. tariff rates, specific to the rare earths, including scandium and yttrium, were unchanged from 1996. Selected rare-earth tariff rates were as follows for countries with "Most favored nation" and "Non-most favored nation" status, respectively: HS 2805.30.0000 rare-earth metals, including scandium and yttrium, whether intermixed or interalloyed, 5.0% ad valorem, 31.3% ad valorem; 2846.10.0000 cerium compounds, 6.2% ad valorem, 35% ad valorem; HS 2846.90.2010 mixtures of rare-earth oxides except cerium oxide, Free, 25% ad valorem; HS 2846.90.2050 mixtures of rare-earth chlorides, Free, 25% ad valorem; HS 2846.90.4000 yttrium-bearing materials and compounds containing by weight greater than 19%, but less than 85% yttrium oxide equivalent, Free, 25% ad valorem; HS 2846.90.8000 individual rare-earth compounds, including oxides, nitrates, hydroxides, and chlorides (excludes cerium compounds, mixtures of rare-earth oxides, and mixtures of rare-earth chlorides) 3.7% ad valorem, 25% ad valorem; HS 3606.90.3000 ferrocerium and other pyrophoric alloys, 5.9% ad valorem, 56.7% ad valorem; HS 7202.99.5040 ferroalloys, other (rare-earth silicide), 5.0% ad valorem, 25% ad valorem; HS 7601.20.9090 aluminum alloys, other (including scandium-aluminum alloys), Free, 10.5% ad valorem.

Special rare-earth tariffs for Canada and Mexico were the result of Presidential Proclamation 6641, implementing the North American Free Trade Agreement (NAFTA), effective January 1, 1994. Under the agreement, Canada's and Mexico's tariff rates for most rare-earth products were granted free status except as follows: Imports from Mexico of rare-earth metals (HS 2805.30.0000) have a 1% ad valorem tariff and aluminum alloys, other (HS 7601.20.9090), have a 1.2% ad valorem tariff. Tariff rates for most other foreign countries were negotiated under the Generalized Agreement on Tariffs and Trade (GATT) Uruguay Round of Multilateral Trade Negotiation. New staged rate schedules taking effect January 1, 1996, were negotiated at the GATT Uruguay Round of negotiations in 1994.

## Stocks

U.S. Government stocks of rare earths in the NDS classified as committed for sale-pending shipment were 386 tons (425 short tons) at yearend 1997. Stocks held in the NDS classified as subspecification excess material were 85.7 kilograms (189 pounds). Rare-earth stocks held in the stockpile were contained in sodium sulfate and inventoried on a contained-REO basis.

## Prices

List prices for rare-earth prices were unchanged in 1997. The following prices were estimated based on domestic trade data from various sources. The price of cerium carbonate in 1997 was estimated at \$3.80 to \$4.50 per kilogram. Cerium oxide was estimated at \$25.00 to \$27.00 per kilogram. Mixed rare-earth

# BEST AVAILABLE COPY

chloride prices averaged \$3.87 per kilogram. All rare-earth prices remained nominal and subject to change without notice. Competitive pricing policies remained in effect with prices for most rare-earth products quoted on a daily basis.

The estimated market price for bastnasite concentrate was \$2.87 per kilogram. The price of monazite concentrate, typically sold with a minimum 55% rare-earth oxide including thoria, free-on-board (f.o.b.) as quoted in U.S. dollars and based on U.S. import data, was \$400 per ton. The 1997 monazite price increased from the 1996 price range, as converted from Australian dollars (A\$), of US\$244 to US\$285 (Metal Bulletin, 1996). The 1997 price of monazite on a contained-REO basis sold for \$0.73 per kilogram.

The price range of mischmetal (a natural mixture of rare-earth metals that typically form by metallothermic reduction of a mixed rare-earth chloride) was \$6.80-\$12.00 per kilogram at yearend 1997 (Elements, 1997). Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 1997, as shown in table 3. (See table 3.)

No published prices for scandium oxide in kilogram quantities were available. Yearend 1997 nominal prices for scandium oxide per kilogram were compiled from information from several domestic suppliers and processors. Prices were unchanged from yearend 1996 and were listed as follows: 99% purity, \$1,400; 99.9% purity, \$2,900; 99.99% purity, \$4,400; and 99.999% purity, \$6,750.

Selected scandium metal prices for 1997, as listed by the Johnson Matthey Alfa AESAR catalog, were as follows: 99.99% REO purity, lump, sublimed dendritic, ampouled under argon, \$172 per gram; 99.9% REO purity, <250-micron powder, ampouled under argon, \$570 per 2 grams; and 99.9% purity, lump, sublimed dendritic lump, ampouled under argon, \$262 per 2 grams; 99.9% REO purity, foil, 0.025 millimeter thick, packaged under argon, 25 millimeters by 25 millimeters, \$96.90 per item (Alfa AESAR, 1997-98).

Selected scandium compound prices for 1997, as listed by Aldrich Chemical Co., were as follows: scandium acetate hydrate 99.9% purity, \$42.30 per gram; scandium chloride hydrate 99.99% purity, \$56.90 per gram; scandium nitrate hydrate 99.9% purity, \$54.80; and scandium sulfate pentahydrate 99.9% purity, \$60.05 per gram. Prices for standard solutions for calibrating analytical equipment were \$21.85 per 100 milliliters of scandium atomic absorption standard solution and \$338.15 per 100 milliliters of scandium plasma standard solution (Aldrich Chemical Co., 1996-97).

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost of the oxide while higher purity distilled scandium metal have averaged about five times the cost.

## Foreign Trade

Exports and imports of rare earths decreased in 1997. U.S. exports totaled 12.7 million kilograms valued at \$78.7 million, a 6% decrease in quantity and a 0.5% decrease in value. Imports totaled 16.9 million kilograms gross weight valued at \$131 million, a 29% decrease in quantity and a 5% decrease in value compared with those of 1996.

Exports of rare earths decreased in three out of four trade categories in 1997. The United States exported 825,000 kilograms of rare-earth metals, a 297% increase from that of 1996, valued at \$5.7 million, the result of increased demand for low-value alloyed rare-earth metals. Principal destinations in descending order were Japan, Germany, the United Kingdom, and Taiwan. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, decreased 3% to 5,890,000 kilograms valued at \$38.4 million. Major destinations were the Republic of Korea, Germany, Malaysia, Singapore, India, and Canada. (See table 4.)

Exports of inorganic and organic rare-earth compounds decreased from 2.21 million kilograms in 1996 to 1.66 million kilograms in 1997, while the value of the shipments increased 14% to \$17.7 million. Shipments, in descending order of quantity, were to Japan, Colombia, Brazil, Canada, and Taiwan.

U.S. exports of ferrocérium and other pyrophoric alloys decreased from 4.97 million kilograms to 4.31 million kilograms valued at \$16.9 million. Principal destinations were Canada, Germany, the United Arab Emirates, and Singapore.

The approximate distribution of imports based on analysis of Journal of Commerce data was as follows: automotive catalytic converters, 55%; permanent magnets, 15%; glass polishing and ceramics, 13%; petroleum refining catalysts, 9%; phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 4%; metallurgical additives and alloys, 2%; and miscellaneous, 2%.

Imports of compounds and alloys increased in five out of seven rare-earth categories, however overall imports decreased 29% in 1997 compared with 1996. China and France dominated the import market, especially for mixed and individual rare-earth compounds. (See table 5.)

Cerium compounds accounted for 2.71 million kilograms of imports valued at \$18.8 million. The quantity of cerium compounds imported decreased 43% after a record high-year in 1996. Demand decreased primarily for compounds used in automotive exhaust catalysts. China was the dominant supplier for the third year in a row, followed by France and Japan.

Imports of yttrium compounds containing between 19 weight-percent and 85 weight-percent oxide equivalent (yttrium concentrate) increased 15% in 1997. The principal import sources were China, France, and the United Kingdom.

Individual rare-earth compounds, excluding cerium compounds, accounted for the major share of rare-earth imports. Imports declined 38% in 1997 to 9.42 million kilograms valued at \$69.0 million. The major sources of individual rare-earth compounds were China and France, with the value of the imports increasing 2%.

Imports of mixtures of rare-earth oxides, other than cerium oxide, increased 6.7% to 938,000 kilograms valued at \$17.7 million. Principal sources in descending order were China, the Republic of Korea, Japan, and Austria. Imports of rare-earth metals and alloys into the United States totaled 441,000 kilograms in 1997, a 24% increase from the 1996 level. Valued at \$10.0 million, the principal rare-earth metal sources were China, with lesser quantities from Japan and the United Kingdom. Metal imports increased as demand for mischmetal and other rare-earth alloys increased.

Imports of rare-earth chlorides increased 35.5% in 1997 to 3.16 million kilograms valued at \$12.2 million. Supplies of rare-earth chloride came primarily from China, India, and Japan. Rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts. Imports of ferrocium and pyrophoric alloys increased 13.6% to 136,000 kilograms valued at \$2.07 million. Demand increased primarily for use in lighter flints. Principal suppliers in descending order were France, Brazil, and Austria.

## World Review

China, India, and the United States were major sources of rare-earth chlorides, nitrates, and other concentrates and compounds. Thorium-free intermediate compounds were still in demand as refinery feed as industrial consumers expressed concerns with radioactive thorium's potential liabilities, the costs of complying with environmental monitoring and regulations, and escalating costs at approved waste disposal sites. Demand for rare earths decreased in the United States and several other foreign countries as several world economies faltered, especially in Southeast Asia.

World reserves of rare earths were estimated by the U.S. Geological Survey at 100 million tons of contained REO. China has the largest share of world reserves with 43%.

**Australia.**—Jervois Mining NL announced the discovery of a nickel-cobalt-scandium deposit at Lake Innes, New South Wales. The laterite deposit is the result of weathering of a serpentine and reportedly contains 12.4 million tons of ore. The ore contains a metal equivalent 80 thousand tons of nickel, 11 thousand tons of cobalt, and 500 tons of scandium. Scandium grade of the deposit is reported at 76 parts per million, higher than the Earth's crustal average of 22 parts per million. A feasibility study of the Lake Innes laterite deposit is planned for 1998 (Australian Rare Earth Newsletter, accessed January 29, 1998, at URL <http://www.ozemail.com.au/~marcus/aren/jervois.html>).

Australia is the largest producer of heavy mineral sands in the world. In 1997, major producers of heavy mineral concentrates were RGC Ltd., Westralian Sands Ltd. (WSL), Tiwest Joint Venture, Cable Sands Ltd. (CSL), and Consolidated Rutile Ltd. (CRL). Although monazite was not separated during processing for ilmenite, rutile, and zircon, significant quantities could be recovered as a byproduct if demand were to increase.

BHP Titanium Minerals (formerly Mineral Deposit Ltd.) produced minerals from its three mines at Viney Creek and Fullerton, New South Wales, and from its Beenup operation in Western Australia. BHP's New South Wales operations at Viney Creek processed up to 2,500 tons of ore per hour, the Fullerton plant operated at up to 1,200 tons per hour, and the Beenup operation processed up to 3,500 tons per hour. Wet concentrate from the two New South Wales Mines was processed at the Hawks Nest dry separation plant (BHP Titanium Minerals, accessed May 21, 1998, at URL <http://www.bhp.com.au/aboutbhp/fastfacts/titanium.html>).

BHP Titanium Minerals Pty. Ltd.'s Beenup project in Western Australia was commissioned in early 1997. At full capacity, the dredging operation is designed to process 3,500 tons per hour. The Beenup dry plant capacity was expected to produce 600,000 tons per year of ilmenite and 20,000 tons per year of zircon. Shipments of heavy-mineral concentrates began in 1997 (Broken

Hill Proprietary Company, 1997). The Beenup Mine reportedly operated significantly below capacity levels in 1997 due to startup problems. (Minerals Sands Report, 1998a).

Tiwest Joint Venture, an Australian collaboration of Kerr-McGee Corp. (USA) and Minproc Holdings, operated a heavy-mineral sands mine at Cooljarloo, Western Australia. Reserves at the deposit were 177 million tons of sands grading 3.7% heavy minerals. The economic heavy-mineral fraction of the sands grades 4.5% rutile, 61.3% ilmenite, 3.3% leucoxene, and 11.1% zircon. Production in 1997 was 234,000 tons of heavy minerals, an increase of 57% from 1996, but essentially the same as in 1995 (Kerr-McGee Corp., 1998). Monazite content of the Cooljarloo ore was 0.2%, equivalent to about 5% of the heavy mineral assemblage (Jackson and Christiansen, 1993, p. 46-47).

RGC Ltd. discovered two heavy-mineral sands deposits near Ouyen in northwestern Victoria. The onshore deposits, contained heavy minerals in ancient beach strand lines covered by 15 to 30 meters of sediments. The heavy mineral ore zone is reportedly 5 to 10 meters thick, up to 120 meters wide, and tens of kilometers in length (The University of Adelaide, Geology Honours Project Topics for 1998, accessed June 4, 1998, at URL [http://geology.adelaide.edu.au/hons\\_98.html](http://geology.adelaide.edu.au/hons_98.html)).

CRL moved the dredge and floating concentrator from its exhausted Bayside deposit to its Ibis-Alpha heavy-mineral deposit on North Stradbroke Island. During the transition, the plant was upgraded to process up to 3,000 tons of sand per hour. Both CRL dredges reportedly operated at full capacity during the year (Mineral Sands Report, 1998a). Average mineral grades on North Stradbroke Island were 1.5% heavy minerals with a monazite content of 0.0015% (Jackson and Christiansen, 1993, p. 48-49).

WSL reported decreased production of heavy mineral sands in 1997. Decreased ore grades in the current mining area were the primary reason for the decline. Production was expected to increase in 1998 as a result of increased processing of ilmenite (Mineral Sands Report, 1998c). Average monazite grade at the Yoganup Extended Mine in Western Australia was 0.056%, with an above average heavy mineral sands grade of 13.5% (Jackson and Christiansen, 1993, p. 48-49).

CSL ceased heavy mineral sands production at its Waroona Mine in Western Australia at midyear. The plant was moved to its Yarloop deposit, 55 kilometers northeast of Bunbury. CSL also produced heavy mineral concentrates at its Jangardup Mine (Mineral Sands Report, 1998b).

**Brazil.**—Rare-earth reserves in monazite occur in five states in southern Brazil. Measured reserves were 16,622 tons grading 53.88% REO in Bahia, 29,210 tons grading 57% REO in Ceara, 697,382 tons grading 60% REO in Espirito Santo, 326,766 tons grading 59.72% REO in Minas Gerais, and 17,166 tons grading 60% REO in the state of Rio De Janeiro (Anuário Mineral Brasileiro, 1996).

**China.**—The China Government's State Planning Commission announced it would put new rare-earth projects on hold to reduce overproduction. Chinese production reportedly outpaced domestic demand and exports in 1996 resulting in decreased rare-earth prices (Industrial Minerals, 1997b). The Bayan Obo Mine in Inner Mongolia remained the world's leading supplier of rare earths.

China's 1997 rare-earth mineral production was 53,250 tons of

REO, a 3.8% decrease from the 1996 level. Production of processed rare-earths reached 46,500 tons of REO, an increase of 2.6%, while exports totaled 31,400 tons REO, a 2% increase from that of 1996. Regional production was reported as follows: Baotou, Inner Mongolia Autonomous Region, 35,000 tons REO; Shandong Province, 1,200 tons REO; Sichuan Province, 11,000 tons of REO; monazite concentrate production, all regions, 50 tons REO; and ion-adsorption (lateritic) clays, all regions, 6,000 tons (China Rare Earth Information, 1998).

**France.**—Rhône-Poulenc (RP) of France announced it had purchased a 41% stake in the joint venture Chinese rare-earth company Baotou Luxi Rare Earths Company, Ltd. Renamed, Baotou Luxi Rhône Rare Earths Company Limited, the company is 40% owned by the Baotou Rare Earth Development Zone (China) and 19% owned by West Lake (USA) (Rhône-Poulenc, 1997). The joint venture was expected to use RP technology to produce rare-earth containing nickel metal hydride rechargeable battery alloys. The plant is located in Baotou, Inner Mongolia, and was constructed in 1994 (Insight, 1997).

**South Africa.**—Rare Earth Extraction Co. received approval to begin mining monazite at the Steentampskaal deposit north of Vanrhynsdorp, Cape Province. The Steentampskaal deposit was previously mined for its monazite. Production was expected to begin in 1998 at a rate of 24,000 tons of ore per year. Mine life of the deposit is estimated to be 10 years. Reserves of about 200,000 tons reportedly grade 12.5% REO. Plant capacity is planned at 6,000 tons per year of rare-earth chloride (Industrial Minerals, 1997a).

### Current Research and Technology

Scientists at the U.S. Department of Energy's Ames Laboratory discovered a new class of a magnetic refrigeration alloys that incorporate gadolinium (Percharsky and Gschneidner Jr., 1997a, 1997b). The new alloy, made of gadolinium-silicon-germanium  $Gd_5(Si_2Ge_2)$  has a magnetocaloric effect about twice as large as gadolinium, the previously best known magnetic refrigerant for near room temperature use. Magnetic refrigerants are 30 times more efficient than thermoelectric cooling and can be scaled down to small cooling applications. The efficiency of the new rare-earth alloy reportedly makes it competitive with conventional gas-compression cooling. Use of the gadolinium alloy may also be transferred to home and automobile air conditioning and to household appliances such as refrigerators, freezers, and icemakers (Ames Laboratory, 1997).

Easton Sports, Inc. announced the release of its premier line of baseball and softball bats incorporating a high-strength scandium-aluminum alloy. Released at a sporting goods show in February 1997, the bats were used by the winning teams in the 1997 NCAA College World Series, the 1997 Little League World Series in Williamsport, PA, and the Olympic softball games in Atlanta, GA. Scandium alloy additions to aluminum increases the yield strength as it reduces grain size. The high-strength alloy allows the bats to have thinner walls, less weight, and greater rebound, called the "trampoline effect." The scandium-aluminum alloy was provided by the Ashurst Technology Group, Baltimore, MD (Ashurst Technology Group, accessed January 29, 1998, at URL <http://www.intellation.com/ash/bats.html>).

Ashurst Technology Ltd., of Toronto Canada, announced its Baltimore, MD, subsidiary, Ashurst Technology Group, signed an agreement to provide scandium-aluminum alloy to STX Inc., a leading lacrosse stick producer. Scheduled for production in 1998, the scandium-aluminum lacrosse stick will be the lightest and strongest alloy stick available, even when compared to titanium (Ashurst Signs License Agreement with STX and Receives Order for Scandium Lacrosse Sticks, accessed January 29, 1998, at URL [http://www.twoten.press.net/stories/97/09/15/headlines/BUSINESS\\_Ashurst\\_Lacrosse.html](http://www.twoten.press.net/stories/97/09/15/headlines/BUSINESS_Ashurst_Lacrosse.html)).

Researchers at Kaman Aerospace Corp. developed a rare-earth laser system to detect underwater mines. The airborne countermeasure system, known as "Magic Lantern," uses a blue-green laser wavelength to scan below the water surface. The initial Magic Lantern mine countermeasure system was mounted on the SH-2G Super Seasprite helicopter and is based on the light detection and ranging principle (Military & Aerospace, 1997).

### Outlook

Rare-earth demand is expected to be moderate in the United States after several record high years. The U.S. economy continued to improve in 1997 with inflation staying at a low rate. Consumption of rare earths has continued to increase in most applications. Rare-earth markets are expected to continue to use greater amounts of higher purity mixed and separated products. Long-term demand is expected to continue strong for rare earths used in automotive catalytic converters and permanent magnets, a trend that is expected to continue into the next decade. In the short term, demand for permanent magnets is expected to decline as a result of the economic downturn in Southeast Asia. Future growth is forecast for rare earths in magnetic refrigeration, rechargeable nickel hydride batteries, fiber optics, and medical applications, including magnetic resonance imaging contrast agents and dental and surgical lasers.

World reserves are sufficient to meet forecast world demand well into the 21st century. Several major rare-earth deposits in Australia and China have yet to be developed because world demand is currently being satisfied by existing production. Coupled with the likelihood that new deposits will continue to be located, world resources should be adequate to fulfill demand for the foreseeable future.

Domestic companies have shifted away from radioactive-bearing rare-earth ores. This trend has had a negative impact on monazite-producing mineral sands operations worldwide. Future long-term demand for monazite, however, is expected to increase owing to its abundant supply and recovery as a low-cost byproduct. The cost and space to dispose of radioactive waste products in the United States are expected to continue to increase, severely limiting domestic use of low-cost monazite and other thorium-bearing rare-earth ores.

Domestic demand in 1997 exhibited moderation after the strong growth seen in 1995 and 1996. World markets are expected to continue to be very competitive based on lower wages and fewer environmental and permitting requirements. China and the United States are expected to remain significant rare-earth suppliers, while the future economic restructuring of Eastern Europe and Asia has a large potential for both new sources and

new consumers.

The long-term outlook is for an increasingly competitive and diverse group of rare-earth suppliers. As research and technology continue to advance the knowledge of rare earths and their interactions with other elements, the economic base of the rare-earth industry continues to grow. It is likely that new applications will continue to be discovered and developed.

#### References Cited

ALFA AESAR, 1997, Alfa AESAR 1997-98 catalog: 1997, Ward Hill, MA, p. 466-468.

Aldrich Chemical Co., 1996, Handbook of fine chemicals 1996-1997: St. Louis, MO, 1996, p. 1309-1310.

Ames Laboratory News, 1997, Next generation of materials advances magnetic refrigeration: Ames Laboratory, Office of Public Affairs and Information, Ames, IA, June 10, 2 p.

Anuário Mineral Brasileiro 1996, 1997, Terras-raras e monazita: Departamento Nacional de Produção Mineral, p. 416. (Portuguese)

Broken Hill Proprietary Company, 1997, Annual report 1997: Melbourne, Victoria, Australia, 48 p.

China Rare Earth Information, 1998, China rare earth 1997: China Rare Earth Information Center, Baotou, Inner Mongolia, China, v. 4, no. 3, June, p. 1.

Elements, 1997, Monthly market activity: Elements-Rare Earths, Specialty Metals and Applied Technology, December 17, p. 1.

Industrial Minerals, 1997a, Rareco given go ahead for monazite mine: Industrial Minerals, London, no. 363, December, p. 14.

—1997b, Oversupply puts rare earths projects on hold: Industrial Minerals, London, no. 359, August, p. 10.

Insight, 1997, Rhône-Poulenc expands in China: Insight, Rare-earth Information Center, Ames, IA, v. 10, no. 4, April, p. 2.

Jackson, W.D., and Christiansen, Grey, 1993, International Strategic Minerals Inventory summary report—Rare-earth oxides: U.S. Geological Survey Circular 930-N, 68 p.

Kerr-McGee Corp., 1998, Annual Report 1997: Oklahoma City, OK, 58 p.

Metal Bulletin, 1996, Non-ferrous ores: Metal Bulletin [London], no. 8141, December 31, p. 25.

Military & Aerospace, 1997, Navy moves to ladar for minchunting: Military & Aerospace Electronics, February, v. 8, no. 2, p. 1.

Mineral Sands Report 1998a, CRL and BHP production: Mineral Sands Report (Australia), no. 39, February, p. 11.

—1998b, Other Australian producers: Mineral Sands Report (Australia), no. 39, February, p. 13.

—1998c, WSL production and revenue: Mineral Sands Report (Australia), no. 39, February, p. 10.

Percharsky, V.K., and Gschneidner, Jr., K.A. 1997a, Effect of alloying on the giant magnetocaloric effect of  $Gd_3(Si_2Ge_3)$ : Journal of Magnetism and Magnetic Materials, Elsevier, v. 176, p. L179-L184.

—1997b, Giant magnetocaloric effect in  $Gd_3(Si_2Ge_3)$ : Physical Review Letters, The American Physical Society, v. 78 no. 23, p. 4494-4497.

Rhône-Poulenc Press Release, 1997, Rhône-Poulenc, the Baotou Rare Earth Development Zone and West Lake join forces to develop the rare earths market in China: Rhône-Poulenc, Paris, France, March 27, p. 1.

Unocal Corporation, 1998, Annual Report 1997: El Segundo, CA, 72 p.

#### SOURCES OF INFORMATION

##### U.S. Geological Survey Publications

International Strategic Minerals Inventory summary report—Rare-earth oxides: U.S. Geological Survey Circular 930-N, 1993.

Rare-earth elements. Ch. in United States mineral resources, U.S. Geological Survey Professional Paper 820, 1973.

Rare Earths. Ch. in Mineral Commodity Summaries.<sup>1</sup>

Scandium. Ch. in Mineral Commodity Summaries.<sup>1</sup>

Thorium. Ch. in Mineral Commodity Summaries.<sup>1</sup>

Yttrium. Ch. in Mineral Commodity Summaries.<sup>1</sup>

##### Other

American Metal Market, daily.

China Rare Earth Information Newsletter (China).

Elements: Rare Earths, Specialty Metals, and Applied Technology.

European Rare-Earth and Actinide Society (ERES) Newsletter (Switzerland).

Industrial Minerals (London), monthly.

Metal Bulletin (London), semiweekly.

Rare-earth elements and yttrium. Ch. in Mineral facts and problems, U.S. Bureau of Mines Bulletin 675, 1985.

Rare-earth Information Center INSIGHT.

Rare-earth Information Center News.

Roskill Information Service Ltd. (London). The Economics of Rare Earths, 9th edition, 1994.

Unocal Corp. annual report.

<sup>1</sup>Prior to January 1996, published by the U.S. Bureau of Mines.